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Laser polarimetry of human biological tissues as an effective method of differential diagnosis, using the prostate gland as an example

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ABSTRACT

Laser polarimetric technologies (LPT) for the assessment of biological tissues (BT) are a promising scientific direction of research, which is based on the evaluation of changes in the light beam that illuminates the examined tissue. These methods have proven themselves well in many medical fields, such as oncology, gynecology, operative surgery, pathological anatomy, forensic medicine, etc., and allow us to establish pathological changes in BT, the temporal dynamics of these changes, and also expand our knowledge about the morphological structure of various tissues and body systems. In this work, we demonstrated the possibility of using Muller-matrix polarization tomography (MMPT) of linear birefringence (LB) of fibrillar structures of histological preparations of the prostate gland (PG) for the recognition of adenomas, poorly differentiated carcinomas and normal tissues. Histological sections of PG (normal n=30, adenoma n=60, carcinoma n=60) were studied by means of differential MMPT LB of fibrillar structures of preparations with further statistical processing of the obtained results. Calculations of the *M*, *V*, *As* and *Ex*, which characterize the polarization-reproduced diffuse tomograms of the LB were statistically significant (p_1; p_2; $p_{1;2}<0.05$) for diagnostic use in differentiation tumor processes of the PG. As a result of the calculation of the balanced accuracy of statistical processing of coordinate distributions of the LB value of all groups for the differential diagnosis of adenoma and poorly differentiated prostate carcinoma samples in comparison with normal tissue, satisfactory (*V*→*81.3%*) and excellent level of values (*M, As, Ex* →*85-93%*) were established).

Keywords: biological tissues, polarization, laser polarimetry, laser, microscopic samples, Mueller's matrix.

1. INTRODUCTION

As a result of the rapid development of technologies, new opportunities are opening up every year in the field of health care. To date, information

technologies have been introduced in almost the entire field of health care, which has given medicine new features and opportunities. This ensures active changes in medical science and practice. Modern technologies help scientists accumulate and effectively use the information obtained regarding the structure and functions of individual cells and tissues of the human body, including at all stages of the pathological process and its treatment, which is most important for medical science, are invaluable in scientific knowledge (Lang, 2022).

A rather popular field of research nowadays is the mix of medicine and physics, in particular the using of a laser. Such new developments and inventions help facilitate the diagnosis and treatment of patients as efficiently and easily as possible. In biomedical optics, polarized rays plays a major role in recognizing and understanding the processes of electromagnetic wave conversion by optically anisotropic structures of human BT. The analysis of polarization properties, known as polarimetric diagnostics, of various BT has great prospects (Tuchin, 2015). The study of the literature data, it should be noted a large number of scientific works dedicated to achievements in various fields of medicine obtained by LPT, in particular in forensic medicine, traumatology, hematology, oncology, gynecology (Bachinskyi et al., 2018; Olar et al., 2019; Ushenko et al., 2021). Scientific developments using LPT provide the thoroughgoing information about diagnostic objects, changes in their structure depending on various pathological conditions, by evaluating their ability to absorb and scatter light rays and change its polarization.

This paper presents the usefulness of LPT in morphological and clinical studies using the example of differentiation of healthy and pathologically changed PG. This object of study was chosen due to the prevalence of damage of this organ among men all over the world and the ease of collecting material for research. Timely diagnosis of tumor processes of the PG can significantly improve treatment results and save patients' lives. We would like to emphasize the importance of tissue differentiation, in this case between adenoma and malignant (carcinoma) types of PG (Grönberg, 2003). It is the optical analysis of tissues that has clear advantages over other methods: it does not destroy the tissue, which allows you to reproduce the result, does not require training and high qualification of specialists, and does not require large expenditures of money and time.

In this work, we would like to demonstrate the results of multichannel probing with differently polarized laser beams of histological sections of PG with algorithmic reproduction of tomograms of the average value of LB of fibrillar structures of biological layers (PG) for the differentiation of such pathological conditions as benign adenoma and prostate cancer by statistical analysis of the dynamics of changes in sections of preparations.

2. METHODS

The collection of material and its research was carried out from September 2021 to June 2022. The object of the study was histological sections of PG, obtained from 150 patients, aged 52 to 78 years. All samples were divided into two experimental groups: n=60 samples of PG adenoma (1 group) and n=60 samples of poorly differentiated carcinoma (2 groups). BT samples of normal PG from the dead persons due to the cardiovascular diseases were used for control (control group, n=30). Native histological sections of the studied PG were made by freezing microtome. The measurement was performed using a standard polarimeter (Figure 1). The research was carried out using the method of polarization reconstruction of LB of molecular structures. The optical and metrological parameters of the Stokes polarimeter are presented in detail in a series of publications (Ushenko et al., 2021; Borovkova et al., 2019). The obtained results were processed according to standard algorithms of MATLAB and Statistica software products (Everitt, 2021).

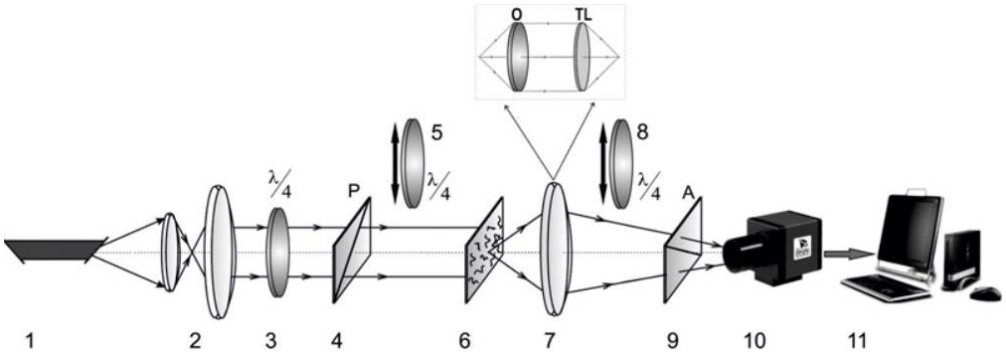

Figure 1 Sheme of the laser polarimeter used for evaluation of histological sections of the PG: 1— laser; 2— collimator; 3, 5, 8— quarter wave plates; 4, 9— polarizer and analyzer; 6— PG; 7— optical system; 10— CCD camera; 11— PC.

The methodology is based on the monitoring of changes in statistical parameters that characterize pathological changes in the structure of BT, which stemmed from the algorithm developed by the scientific group under the leadership of prof. Bachinskyi V.T., Bukovynian State Medical University (Bachinskyi et al., 2020; Bachinskyi et al., 2018; Vanchulyak et al., 2019).

3. RESULTS

Figure 2 shows the diffuse tomograms of the distributions of the LB of optically active molecular complexes of histological sections of the PG from 1 and 2 experimental groups.

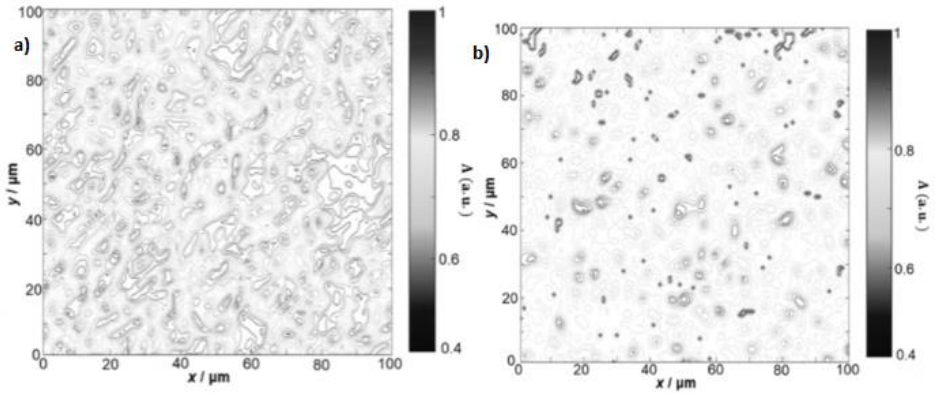

Figure 2 Tomograms of coordinate distributions of LB values of depolarization maps of histological biopsy section of PG adenoma (a) and poorly differentiated PG carcinoma (b)

The obtained results of processing polarimetric images of PG samples in normal and pathological conditions are characterized by different degrees of depolarization of the incident light. This is due to the different density and structural features of normal cells, fibrosis and tumor tissue of each of the studied samples. Significant differences in the tomographic structure of LB tomograms of histological sections of PG from the control group and in cases of oncological conditions were revealed. Through statistical data processing, the following characteristics of digital monitoring of changes in the values of statistical moments of 1-4 orders (mean *M*, variance *V*, asymmetry *As* and excess *Ex)*, which characterize the coordinate maps of the tomographic structure of optical tissue activity of representative samples of microscopic preparations of the PG from the control and experimental groups, were established. The results of statistical analysis and their comparison for different research groups are shown in the table 1. A decrease in the value of *M* and *V* was observed, as well as an increase in the values of *As* and *Ex*, which characterize the distributions of the value of LB of samples of histological sections of the PG from all groups.

Table 1 Statistical moments of the 1st - 4th orders, which characterize the coordinate distributions of the diffuse tomography of LB of samples of histological sections of the PG from control and experimental groups

Sample	Histological sections of the передміхурової залози		
Parameters	Control Group (n=30)	group 1 (samples of prostate adenoma) (n=60)	group 2 (samples of poorly differentiated prostate carcinoma) (n=60)
Mean (M x10^{-2})	1.015 ± 0.004	0.93 ± 0.008	0.86 ± 0,018
$p_1;p_2$		p_1<0.05	p_2<0.05
$p_{1;2}$		$p_{1;2}$<0.05	
Variance (V x10^{-2})	1.29 ± 0.006	1.18 ± 0.009	0.91 ± 0,011
$p_1;p_2$		p_1<0.05	p_2<0.05
$p_{1;2}$		$p_{1;2}$<0.05	
Asymmetry (As)	0.93 ± 0.013	1.26 ± 0,015	1.33 ± 0.025
$p_1;p_2$		p_1<0.05	p_2<0.05
$p_{1;2}$		$p_{1;2}$<0.05	

Excess (*Ex*)	1.01 ± 0.016	1.92 ± 0.026	2.03 ± 0.038
$p_1;p_2$		$p_1<0.05$	$p_2<0.05$
$p_{1;2}$		$p_{1;2}<0.05$	

Calculations of the *M*, *V*, *As* and *Ex*, which characterize the polarization-reproduced diffuse tomograms of the LB were statistically significant ($p_1;p_2;p_{1;2}<0.05$) for diagnostic use in differentiation tumor processes of the PG. Calculating the balanced accuracy of statistical processing of coordinate distributions of the LB value of all groups for the differentiation of adenoma and poorly differentiated carcinoma of PG samples in comparison with normal tissue, satisfactory (V→81.3%) and excellent level of values (M, As, Ex →85-93%) were established (Table 2).

Table 2 Operational characteristics of the strength of the method of diffuse tomography LB of histological sections of the PG.

Sample	Histological sections of the PG							
Parameters	*M*		*V*		*As*		*Ex*	
Se,%	a=126 b=24	84,0	a=122 b=28	81,3	a=141 b=9	94,0	a=141 b=9	94,0
Sp,%	a=130 b=20	86,6	c=122; d=28	81,3	c=136; d=14	90,6	c=139; d=11	92,6
Ac,%	n=150	85,3	n=150	81,3	n=150	92,3	n=150	93,3

4. DISCUSSION

In recent decades, optical methods of forming layer-by-layer images of biological objects using polarized light have become widely used in biomedical diagnostics. It plays an essential role in understanding and interpreting the processes of conversion of electromagnetic waves by optically anisotropic structures of human biological tissues (Tuchin, 2015). The laser generates a beam with a given wavelength and with a constant phase difference (coherent radiation), allowing to discover the properties of BT and liquid environments of the human body, which are not available for ordinary observation. Indeed, today, progressive techniques are being developed, based on the use of the above-mentioned coherent radiation in combination with its polarization and significantly expanding the possibilities of medical diagnostics. Polarimetric imaging allows detecting any changes in BT, which transforms the polarization of the light beam.

The advantages of these methods are demonstrated in the publications of scientists to solve various issues of medical science and practice (Ghosh et al., 2011; Trifonyuk et al., 2018; Karachevtsev et al., 2020). Many works are devoted to patho-anatomical and forensic medical studies of BT. In particular, in forensic medical practice, the effectiveness of the use of these methods was reflected in the diagnosis of the time of injury formation, the time since death due to various causes, the differentiation of various pathological conditions, the detection of the level and influence of alcohol on the accuracy of determining the time of death, the diagnosis of the cause of death due to acute and chronic myocardial ischemia, poisoning by various toxic factors, death from asphyxia and acute blood loss (Vanchulyak et al., 2019; Bachinskyi et al., 2018; Garazdyuk et al., 2016). The results of the diagnosis of the postmortem interval are impressive.

According to the data published in the articles, it was possible to achieve the accuracy of its determination of 45 minutes in the range of up to 36 hours (Bachinskyi et al., 2021). The research data is very promising and allows for accurate reproducible and statistically reliable results (Bachinskyi et al., 2020; Vanchulyak et al., 2019). No less significant are the results of the application of LP methods in oncology, scientists have demonstrated the possibility of differential diagnosis of histological sections of biopsies of tumors of the endometrium, cervix, mammary gland, etc. (Ushenko et al., 2014; Bachinskyi et al., 2018). However, despite the achievements, this direction of biomedical diagnostics remains understudied and requires further dissemination of this ideology and improvement of methods, creation of digital maps of values for BT of various types of human organs in normal and in pathological conditions.

In this work, the technique of MMPT of LB of fibrillar networks was used to detect and differentiate the type of oncological changes occurring in the PG, and good results were demonstrated. On our opinion, further development of these methods will allow us to achieve significant progress in the diagnosis of the morphological structure of biological objects.

5. CONCLUSION

The method of MMPT of linear birefringence of LB of fibrillar networks of PG for the differentiation of adenoma, poorly differentiated carcinoma and normal prostate tissue is analytically substantiated. In the framework of evidence-based medicine, a high (*V*→81.3%) and excellent level of accuracy (*M, As, Ex* →85-93%) was established for the differentiation of benign and malignant samples of histological sections of prostate tumor biopsies.

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Author Contributions

Author contributed to the research and preparation of the manuscript.

Ethical approval

The study was approved by the Medical Ethics Committee of the Kharkiv National Medical University, Kharkiv, Ukraine. (Protocol No.32 dated 28.07.2022).

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Conflicts of interest

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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